McCRACKEN

Investigation of an
Ore-Handling Train

Civil Engineering

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INVESTIGATION OF AN ORE-HANDLING CRANE

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT WEIR McCRACKEN

ENTITLED INVESTIGATION OF AN ORE-HANDLING CRANE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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Contents.

Article 1.
Description of Bridge.

The Ore Handling Crane, which will be investigated in the following pages is situated at the ore docks of the Illinois Steel Company at South Chicago, Illinois. It is a structure 518 feet, 6$\frac{1}{2}$ inches overall and consists of a dock cantilever arm, 149 feet, 11 inches long; a furnace cantilever arm, 187 feet, 1$\frac{1}{2}$ inches long; and a center span of 181 feet, 6 inches.

The trusses are through riveted, of the Pratt type, and are spaced 25 feet, center to center. They have curved lower chords and sloping upper chords on the cantilever arms. The general dimensions are given on the truss diagram on Plate I. The members are all rigid and those in the center span are designed for alternate tensile and compressive stresses.

The wind bracing is in the

plane of the upper chord. The diagonal members are designed to take tension only.

The crane is supported on two masonry walls, 188 feet center to center. The space between these walls serves as a storage yard for ore, while that outside the walls is used for coke, limestone, etc. used in the blast furnaces. (See Fig 1.) The crane may be moved along the wall and may also be swung around the fixed tower through an angle of about 30 degrees. These conditions admit of great efficiency and speed in the manner of handling the ore and charging materials.

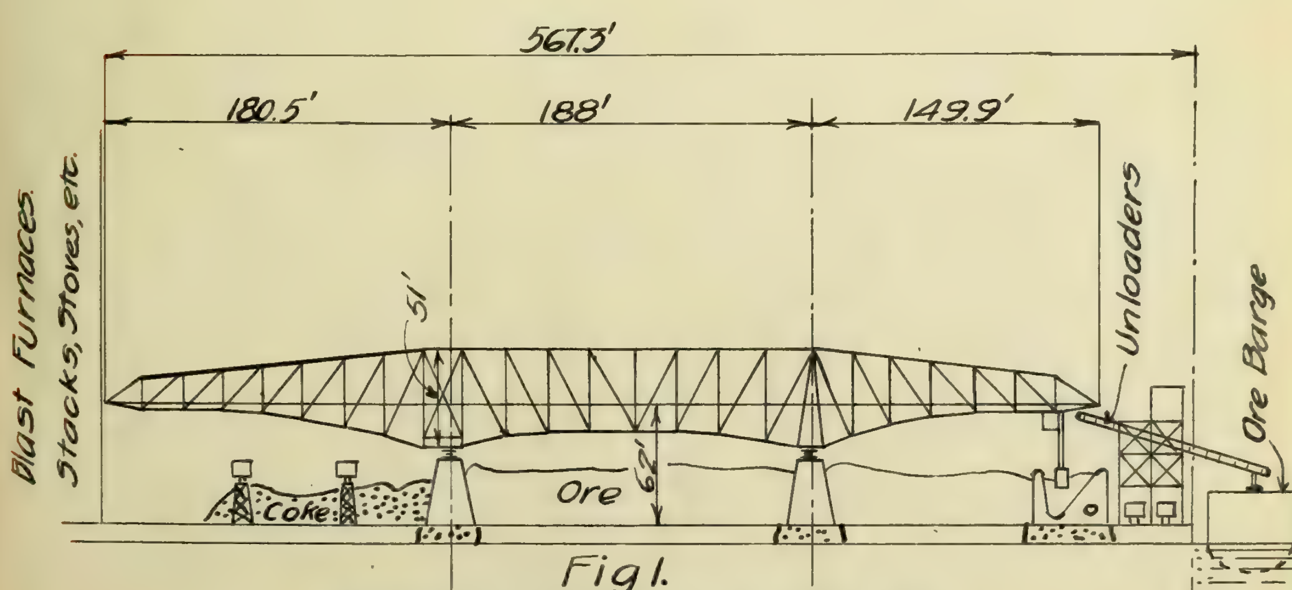


Fig 1.
General Elevation of Storage Yard.

The following investigation consists of the calculation of the stresses in the members of the trusses for all positions of the crane; the stresses in the wind bracing; and the efficiencies of these members. No attempt will be made to calculate the efficiencies of connections on account of the lack of data.

Article 2.
Dead Loads.

a. Loading. The loads used in computing the dead load stresses are those assumed by the designers. They are given on the truss diagram on Plate I, and on Fig. 2.

b. Positions of Truss. It is possible to swing the crane 15 degrees either way from the normal position, the fixed tower being on the wall nearest the docks. This condition varies the lengths of the cantilever arms and the center span. Fig. 2. shows the position of the supports for the normal and extreme positions of the truss

c. Reactions. The reactions for all positions of the crane are computed by ordinary methods. The trusses are considered as simple beams with overhanging ends

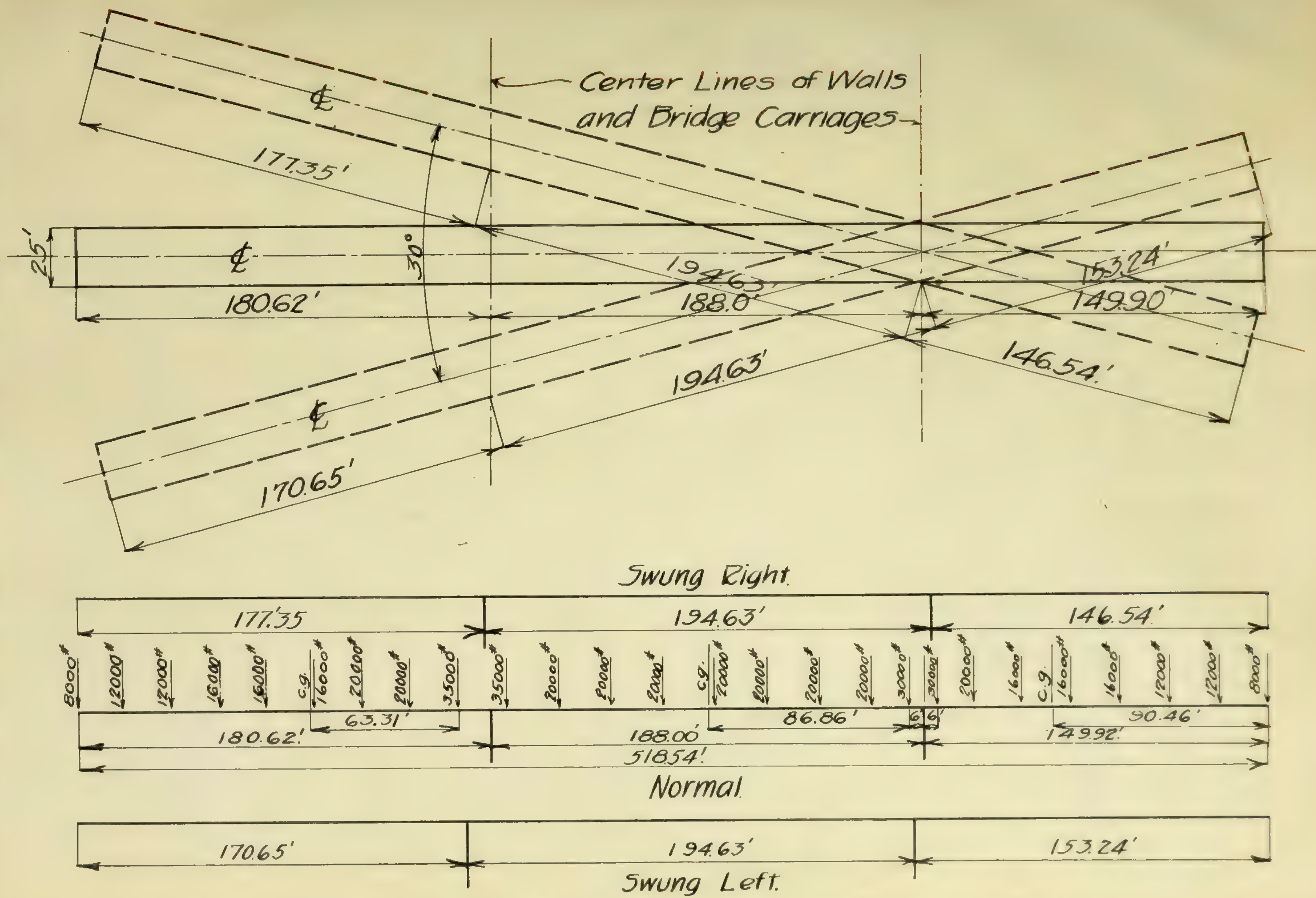


Fig.2. LOCATION OF SUPPORTS FOR NORMAL AND EXTREME POSITIONS.

Fig. 2 shows the centers of gravity of the loads on the truss.

The reactions are given in Table I.

TABLE I

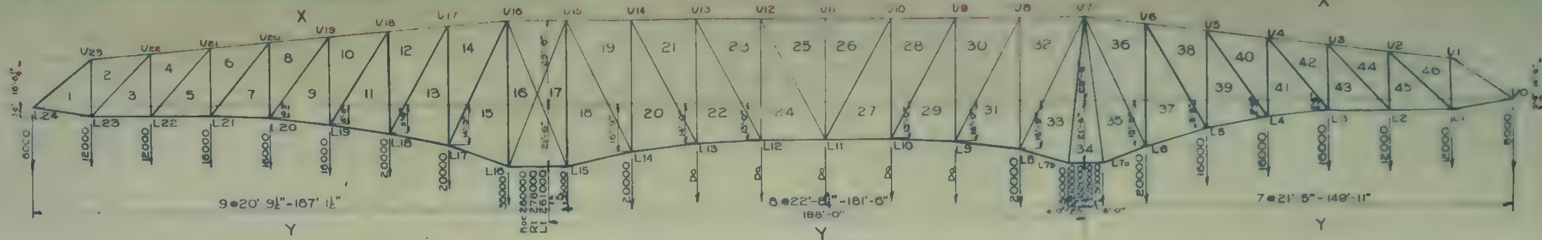
DEAD LOAD REACTION FOR CRANE.

Position of Bridge	R_1	R_2
Normal	280100#	209900#
Swung Right	278100#	211900#
Swung Left	261200#	228800#

d. Stresses. The dead load stresses were computed by graphic statics, the stress diagrams being shown on Plate I, Fig. 1, 2 and 3.

The stresses are given in Table II

PLATE I



TRUSS DIAGRAM

FIG. 1
DEAD LOAD STRESS DIAGRAM
BRIDGE NORMAL

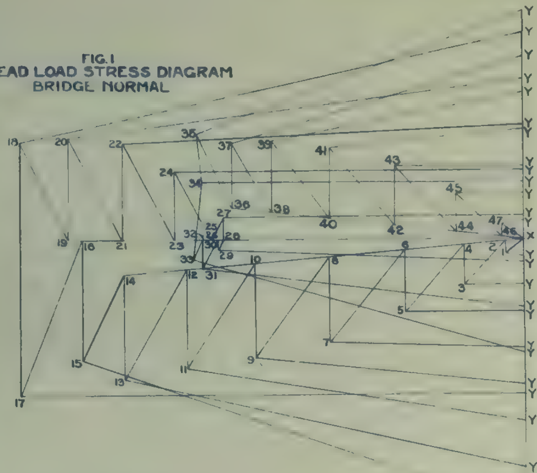


FIG. 2
DEAD LOAD STRESS DIAGRAM
BRIDGE SKEWED RIGHT

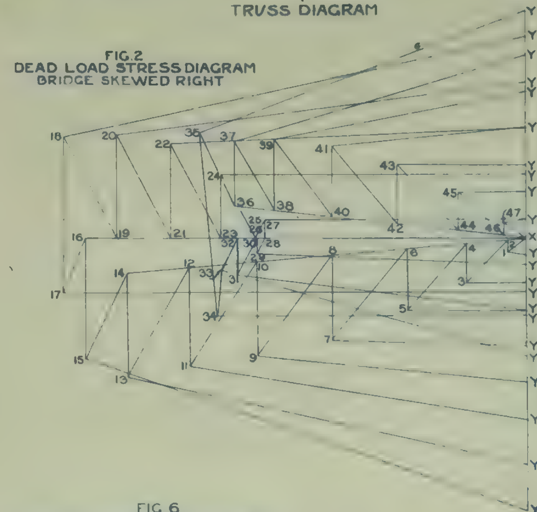
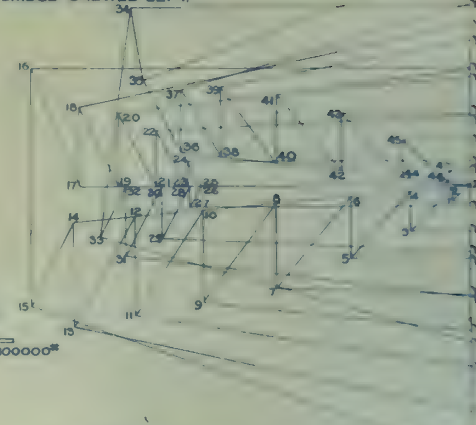
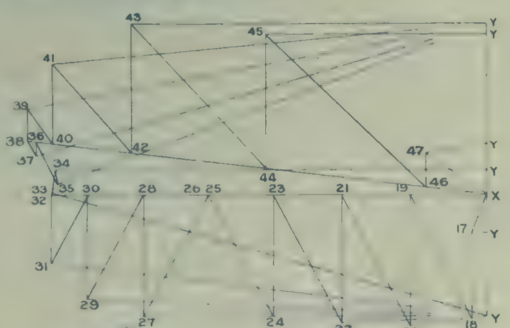


FIG 3.
DEAD LOAD STRESS DIAGRAM.
BRIDGE SKEWED LEFT.



SCALE OF ALL
STRESS DIAGRAMS

FIG. 4
LIVE LOAD STRESS DIAGRAM
CAR AT RIGHT END, BRIDGE NORMAL



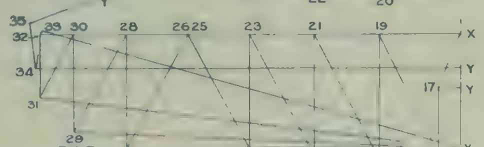


FIG 5
LIVE LOAD STRESS DIAGRAM
CAR AT RIGHT END, BRIDGE SKEWED RIGHT

FIG 6
LIVE LOAD STRESS DIAGRAM
CAR AT LEFT END, BRIDGE SKEWED RIGHT

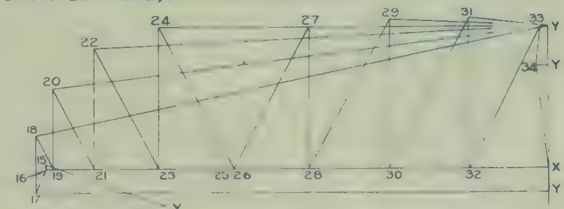


FIG 7
LIVE LOAD STRESS DIAGRAM
CAR AT RIGHT END, BRIDGE SKEWED LEFT

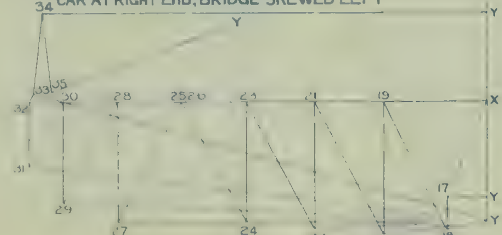


FIG 8
LIVE LOAD STRESS DIAGRAM
CAR AT LEFT END, BRIDGE SKEWED LEFT

FIG 9
LIVE LOAD STRESS DIAGRAM
CAR AT LEFT END, BRIDGE NORMAL

TABLE II

DEAD LOAD STRESSES

MEMBER		POSITION OF BRIDGE			MEMBER		POSITION OF BRIDGE		
Diag'm.	Truss.	Normal.	Swung Right.	Swung Left.	Diag'm	Truss.	Normal.	Swung Right.	Swung Left.
Bottom Chords					Top Chords				
Y-1	L24L23	+8000			X-1	L24U23	-10200		
Y-3	L23L22	+26000			X-2	U23U22	- 8000		
Y-5	L22L21	+52000			X-4	U22U21	-26200		
Y-7	L21L20	+85100			X-6	U21U20	-52100		
Y-9	L20L19	+118600			X-8	U20U19	-85500		
Y-11	L19L18	+149700			X-10	U19U18	-118300		
Y-13	L18L17	+179100			X-12	U18U17	-148000		
Y-15	L17L16	+204400			X-14	U17U16	-175600		
Y-17	L16L15	+220600	+202600	(Y-16)+192700	X-16	U16U15	-193000	-193000	(X-17)-172800
Y-18	L15L14	+225200	+207000	+175000	X-19	U15U14	-199200	-179300	-154900
Y-20	L14L13	+200800	+180800	+155400	X-21	U14U13	-175500	-155600	-137800
Y-22	L13L12	+175800	+155800	+138000	X-23	U13U12	-153000	-133900	-124,900
Y-24	L12L11	+153000	+133900	+124600	X-25	U12U10	-136800	-118800	-118900
Y-27	L11L10	+131300	+114200	+123400	X-28	U10U9	-131600	-114300	-123800
Y-29	L10L9	+134000	+118000	+135700	X-30	U9U8	-133900	-118000	-136000
Y-31	L9L8	+141500	+127300	+152900	X-32	U8U7	-140500	-126700	-152200
Y-33	L8L7b	+150500	+138800	+169000	X-36	U7U6	-128500		
Y-34	L7bL7a	+140900	+135900	+149000	X-38	U6U5	-110900		
Y-35	L7aL6	+152800			X-40	U5U4	- 85300		
Y-37	L6L5	+133000			X-42	U4U3	- 56800		
Y-39	L5L4	+112100			X-44	U3U2	- 29800		
Y-41	L4L3	+ 85000			X-46	U2U1	- 9700		
Y-43	L3L2	+ 56300			X-47	U1L0	- 11700		
Y-45	L2L1	+ 29700							
Y-47	L1L0	+ 9900							

TABLE II (con't)

DEAD LOAD STRESSES

MEMBER		POSITION OF BRIDGE			MEMBER		POSITION OF BRIDGE		
Diag'm.	Truss.	Normal.	Swung Right.	Swung Left.	Diag'm.	Truss.	Normal.	Swung Right	Swung Left.
Diagonals					Vertical Posts				
2-3	$L_{23}U_{22}$	- 26000			1-2	$L_{23}U_{23}$	+ 5700		
4-5	$L_{22}U_{21}$	- 39100			3-4	$L_{22}U_{22}$	+ 17300		
6-7	$L_{21}U_{20}$	- 52300			5-6	$L_{21}U_{21}$	+ 27100		
8-9	$L_{20}U_{19}$	- 55000			7-8	$L_{20}U_{20}$	+ 37500		
10-11	$L_{19}U_{18}$	- 54800			9-10	$L_{19}U_{19}$	+ 41300		
12-13	$L_{18}U_{17}$	- 55100			11-12	$L_{18}U_{18}$	+ 43100		
14-15	$L_{17}U_{16}$	- 41400			13-14	$L_{17}U_{17}$	+ 45700		
16-17	$L_{16}U_{15}$ $L_{15}U_{16}$	* DL - 73100	DL - 26000	DR - 56000	15-16	$L_{16}U_{16}$	+ 52900	+ 52900	+ 104700
18-19	$U_{15}L_{14}$	- 47200	- 50000	- 40500	17-18	$L_{15}U_{15}$	+ 110100	+ 68000	+ 35400
20-21	$U_{14}L_{13}$	- 50400	- 51000	- 36500	19-20	$L_{14}U_{14}$	+ 44800	+ 45000	+ 32100
22-23	$U_{13}L_{12}$	- 48200	- 47000	- 28000	21-22	$L_{13}U_{13}$	+ 42100	+ 41300	+ 24800
24-25	$U_{12}L_{11}$	- 34000	- 31600	- 12500	23-24	$L_{12}U_{12}$	+ 30000	+ 28000	+ 11000
26-27	$L_{11}U_{10}$	+ 11200	+ 9300	- 10000	25-26	$L_{11}U_{11}$	0	0	0
28-29	$L_{10}U_{9}$	- 4900	- 8000	- 26000	27-28	$L_{10}U_{10}$	- 10000	- 8000	+ 9000
30-31	$L_{9}U_{8}$	- 14000	- 18100	- 34500	29-30	$L_{9}U_{9}$	+ 4300	+ 7000	+ 23000
32-33	$L_{8}U_{7}$	- 10000	- 15600	- 25000	31-32	$L_{8}U_{8}$	+ 12700	+ 16000	+ 30300
33-34	$L_{7b}U_{7}$	+ 34000	- 20200	+ 102000	36-37	$L_{6}U_{6}$	+ 28000		
34-35	$L_{7a}U_{7}$	+ 21500	+ 80600	+ 32000	38-39	$L_{5}U_{5}$	+ 31000		
35-36	$U_{7}L_{6}$	- 35900			40-41	$L_{4}U_{4}$	+ 30300		
37-38	$U_{6}L_{5}$	- 34800			42-43	$L_{3}U_{3}$	+ 26000		
39-40	$U_{5}L_{4}$	- 42500			44-45	$L_{2}U_{2}$	+ 16900		
41-42	$U_{4}L_{3}$	- 44500			46-47	$L_{1}U_{1}$	+ 5500		
43-44	$U_{3}L_{2}$	- 39400							
45-46	$U_{2}L_{1}$	- 27600							

* D.L - Down Left.
D.R - Down Right.

Article 3.
Live Loads.

a. Loading. The live load on this crane consists of the weight of the ore car and its load. This weight is assumed as 75 tons, making the load on one truss 75,000 pounds. The car runs on 4 axles spaced 7 feet center to center, and one-fourth of the load is considered on each axle. The live load is, therefore, a 4-wheeled load of 18750 pounds with wheels spaced 7-foot centers. The extreme position of the car is 6 feet from the end.

b. Reactions. The reactions under live load are computed, considering the trusses as simple beams with overhanging ends.

Positions of the load for which the reactions are computed are those which will give maximum stresses in the various members. The car at the end of the canti-

lower arm gives maximum tension in the upper chord members and maximum compression in the lower chord members. The position of the car is shown in Fig. 3 and 4. The reactions are given in Table III.

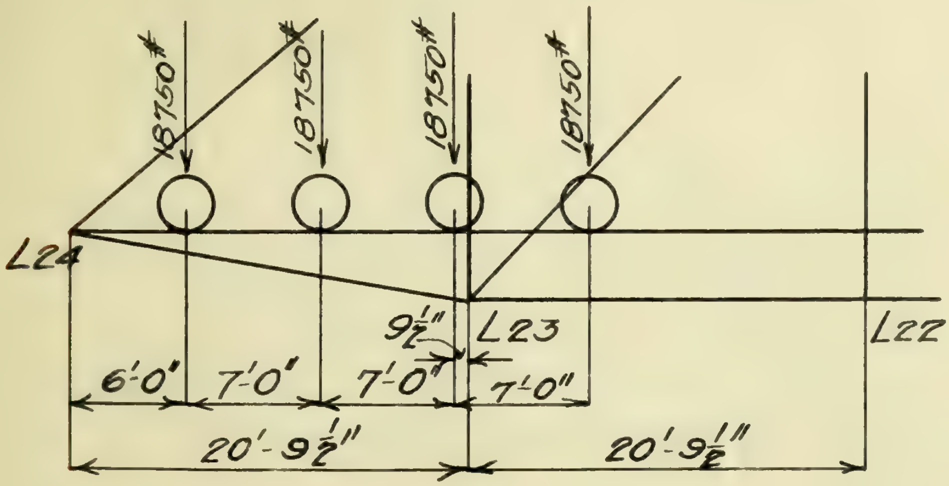


Fig. 3.
Extreme Position of Car on Furnace Cantilever.

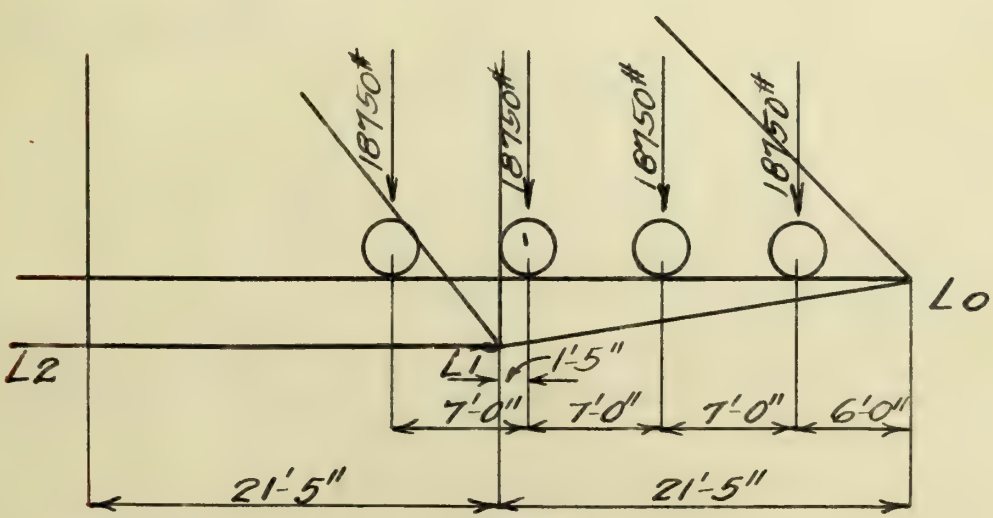
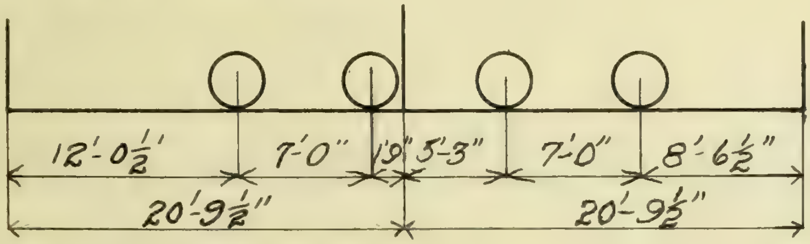


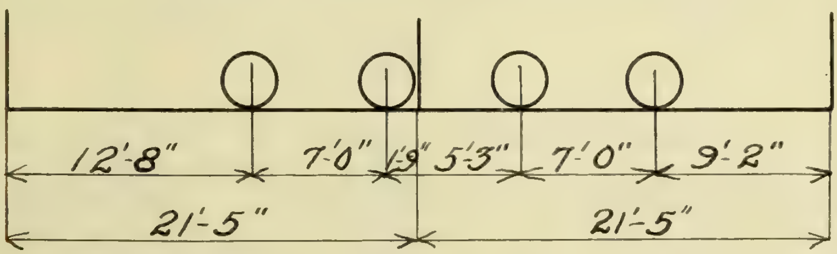
Fig. 4.
Extreme Position of Car on Dock Cantilever.

For maximum stresses in the vertical posts the car is placed so as to give the maximum floor beam reaction. (See Fig. 5,6 and 7). These positions also give maximum stresses in the diagonals in the cantilever arms. The computation of reactions is unnecessary for the determination of these stresses.



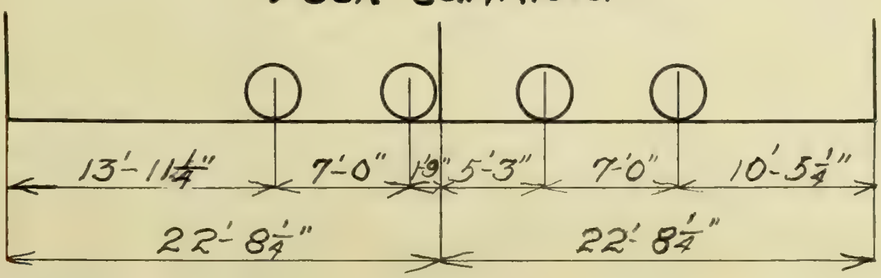
Max F.B.R.= 49700# Fig 5

Furnace Cantilever.



Max FBR=50460# Fig 6

Dock Cantilever



Max FBR=51850# Fig. 7.

Center Span.

Positions of Car for Maximum Floor Beam Reactions.

TABLE III

LIVE LOAD REACTIONS

CAR AT ENDS OF CANTILEVERS

POSITION OF BRIDGE	LOCATION OF CAR	R_1	R_2
Normal	Right End	-53,200#	+128,200#
	Left End	+140,800.	- 65,800.
Right	Right End	- 52800.	+ 127,800.
	Left End	+134500.	- 59,500.
Left	Right End	- 50,100	+ 125,100
	Left End	+136,900	- 61,900

TABLE IV.

LIVE LOAD REACTIONS

MAXIMUM BENDING MOMENTS IN CENTER SPAN

POSITION OF CAR.		REACTION R_1.			BENDING MOMENT.		
		POSITION OF BRIDGE.			POSITION OF BRIDGE.		
Point	Wheel.	Normal.	Right.	Left.	Normal.	Right.	Left.
0	1	68400#	67300#	64600#	444,000#'	657,000#'	1,054,000#'
1	1	59100	58400	55800	1,724,000	1,900,000	2,183,000
2	2	52900	52400	49800	2,609,000	2,769,000	2,944,000
3	2	48300	43600	41000	3,130,000	3264,000	3,339,000
4	2	34800	35000	32400	3,254,000	3,389,000	3,339,000

TABLE V.

LIVE LOAD REACTIONS

MAXIMUM SHEAR IN CENTER SPAN.

POSITION OF CAR		REACTION R_1.			SHEAR		
		POSITION OF BRIDGE			POSITION OF BRIDGE		
Point	Wheel	Normal	Right	Left.	Normal	Right	Left.
0	1	68400	67300	64600	21400	31700	51200
1	1	59100	58400	55800	59100	58400	55800
2	1	50000	49600	47200	5000	49600	47200
3	1	41000	41100	38400	41000	41100	38400
4	1	32000	32300	29700	32000	32300	29700
5	1	23000	23500	20900	23000	23500	20900
6	1	13900	14800	12200	13900	14800	12200
7	1	4900	6000	3400	4900	6000	3400

For the center span, the car in the span gives maximum compression in the upper chord members and maximum tension in the lowers chord members. The position of the car, the reactions, the bending moments, and the shears for all positions of the truss are given in Tables IV and V.

c. Stresses. The stresses for the various loadings given above are computed by graphic statics and ordinary algebraic methods. The diagrams for stresses with the car at the ends of the truss are shown on Plate I, Fig 4, 5, 6, 7, 8 and 9.

The stresses are given in Table VI.

TABLE VI

LIVE LOAD STRESSES.

MEMBER.		CAR AT LEFT END. POSITION OF BRIDGE			CAR AT RIGHT END. POSITION OF BRIDGE			CAR ON CENTER SPAN. POSITION OF BRIDGE		
Diag'm	Truss	Normal.	Swung Right	Swung Left	Normal.	Swung Right	Swung Left	Normal.	Swung Right	Swung Left
Bottom Chords										
Y-1	L24 L23	+ 22000			0					
Y-3	L23 L22	+ 86000			0					
Y-5	L22 L21	+144600			0					
Y-7	L21 L20	+190000			0					
Y-9	L20 L19	+217000			0					
Y-11	L19 L18	+231500			0					
Y-13	L18 L17	+236500			0					
Y-15	L17 L16	+233000			0					
Y-17	L16 L15	+233000	+224600	Y-16 +220500	+ 6900	+ 9900	+ 17000			
Y-18	L15 L14	+238000	+229000	+212500	+ 7000	+ 10000	+ 17600	- 8900	- 13000	- 21100
Y-20	L14 L13	+226500	+218800	+201500	+ 33800	+ 35600	+ 45000	- 37500	- 41300	- 45300
Y-22	L13 L12	+205000	+199000	+182000	+ 63300	+ 64000	+ 75000	- 60200	- 63900	- 68000
Y-24	L12 L11	+174600	+170700	+154700	+ 93300	+ 92000	+105000	- 73600	- 76900	- 78600
Y-27	L11 L10	+104200	+104600	+ 91000	+150000	+146000	+161000	- 73600	- 76900	- 78600
Y-29	L10 L9	+ 67000	+ 69800	+ 58000	+175000	+169000	+185100	- 60200	- 63900	- 68000
Y-31	L9 L8	+ 30000	+ 35000	+ 25000	+192000	+185000	+201500	- 37500	- 41300	- 45300
Y-33	L8 L7b	0	+ 3500	- 4300	+197500	+190000	+206000	*- 8900	- 13000	- 21100
Y-34	L7b L7a	+ 4000	+ 5300	+ 1800	+189000	+185600	+194000			
Y-35	L7a L6	0	0		+201000					
Y-37	L6 L5	0	0		+205600					
Y-39	L5 L4	0	0		+204600					
Y-41	L4 L3	0	0		+191000					
Y-43	L3 L2	0	0		+156000					
Y-45	L2 L1	0	0		+ 97000					
Y-47	L1 L0	0	0		+ 27000					

TABLE VI

LIVE LOAD STRESSES.

MEMBER.		CAR AT LEFT END. POSITION OF BRIDGE.			CAR AT RIGHT END. POSITION OF BRIDGE.			CAR ON CENTER SPAN. POSITION OF BRIDGE.		
Diag'm.	Truss.	Normal.	Swung Right.	Swung Left.	Normal.	Swung Right.	Swung Left.	Normal.	Swung Right.	Swung Left.
Top	Chords.									
x-1	$U_{24}U_{23}$	- 27800			0					
x-2	$U_{23}U_{22}$	- 21800			0					
x-4	$U_{22}U_{21}$	- 86000			0					
x-6	$U_{21}U_{20}$	-145200			0					
x-8	$U_{20}U_{19}$	-191000			0					
x-10	$U_{19}U_{18}$	-217000			0					
x-12	$U_{18}U_{17}$	-229500			0					
x-14	$U_{17}U_{16}$	-232100			0					
x-16	$U_{16}U_{15}$	-220000	-220000	-208000	0			+ 8700	+ 12900	+ 20700
x-19	$U_{15}U_{14}$	-224800	-217000	-200000	- 33800	- 35300	-45000	+ 37300	+ 41100	+ 45000
x-21	$U_{14}U_{13}$	-205000	-199000	-182000	- 63500	- 64000	- 75000	+ 60000	+ 63600	+ 67800
x-23	$U_{13}U_{12}$	-175000	-170700	-154700	- 93900	- 92100	-105000	+ 73600	+ 76900	+ 78600
x-25	$U_{12}U_{10}$	-139600	-137500	-123000	-122000	-119100	-133000	+ 76500	+ 79800	+ 78600
x-28	$U_{10}U_{9}$	-104300	-104600	- 91000	-150000	-146000	-161000	+ 73600	+ 76900	+ 78600
x-30	$U_{9}U_{8}$	- 67000	- 69500	- 58000	-174800	-169000	-185000	+ 66000	+ 63600	+ 67800
x-32	$U_{8}U_{7}$	- 29900	- 34600	- 25000	-190500	-183900	-200000	+ 37300	+ 41100	+ 45000
x-36	$U_{7}U_{6}$	0			-198500					
x-38	$U_{6}U_{5}$	0			-202500					
x-40	$U_{5}U_{4}$	0			-191100					
x-42	$U_{4}U_{3}$	0			-156900					
x-44	$U_{3}U_{2}$	0			- 97500					
x-46	$U_{2}U_{1}$	0			- 27000					
x-47	$U_{1}L_{0}$	0			- 32400					

TABLE VI

LIVE LOAD STRESSES

MEMBER		CAR AT LEFT END POSITION OF BRIDGE			CAR AT RIGHT END POSITION OF BRIDGE			CAR ON CENTER SPAN POSITION OF BRIDGE		
Diag'm.	Truss.	Normal.	Swung Right	Swung Left	Normal.	Swung Right	Swung Left	Normal.	Swung Right	Swung Left
Diagonals.										
2-3	L23U22	- 93000			0					
4-5	L22U21	- 89000			0					
6-7	L21U20	- 72000			0					
8-9	L20U19	- 43000			0					
10-11	L19U18	- 23300			0					
12-13	L18U17	- 5000			0					
14-15	L17U16	- 20500			0					
16-17	L16U15 L15U16	*DL - 33500	DL - 11000	DR - 34000	- 18000	- 25500	- 45200	D.R.* - 23100	D.R.* - 34000	- 55300
18-19	U15L14	- 19000	- 12000	- 18000	+ 61000	+ 58100	+ 63000	- 56800	- 59000	- 56200
20-21	U14L13	- 43000	- 40000	- 39200	+ 64700	+ 61500	+ 66000	- 53000	- 52500	- 50000
22-23	U13L12	- 64000	- 60000	- 58000	+ 63500	+ 60000	+ 64000	- 45000	- 45500	- 42600
24-25	U12L11	- 75000	- 70000	- 67500	+ 60000	+ 57000	+ 60000	- 36400	- 36800	- 34000
26-27	L10U10	+ 75000	+ 70000	+ 67500	- 60000	- 57000	- 60000	+ 26000	+ 26500	+ 23500
28-29	L10U9	+ 78500	+ 74400	+ 72200	- 52000	- 48700	- 50500	+ 15200	+ 16000	+ 13600
30-31	L9U8	+ 78800	+ 75000	+ 70800	- 33600	- 31000	- 32100	+ 5100	+ 6300	+ 3700
32-33	L8U7	+ 73700	+ 70300	+ 65000	+ 1000	+ 2000	+ 4000	0	0	0
33-34	L7bU7	- 33000	- 17800	- 42400	+ 10000	- 17000	+ 35500	+ 37600	+ 16600	+ 58400
34-35	L7aU7	- 33000	- 45200	- 16000	- 6300	+ 19800	- 35000	+ 37600	+ 58400	+ 16600
35-36	U7L6	0			+ 20700					
37-38	U6L5	0			+ 7800					
39-40	U5L4	0			- 22000					
41-42	U4L3	0			- 51000					
43-44	U3L2	0			- 86500					
45-46	U2L1	0			- 97000					

*DL - Down Left.
D.R. - Down Right.

TABLE VI

LIVE LOAD STRESSES

MEMBER		CAR AT LEFT END			CAR AT RIGHT END			CAR ON CENTER SPAN		
		POSITION OF BRIDGE			POSITION OF BRIDGE			POSITION OF BRIDGE		
Diag'm	Truss	Normal.	Swung Right	Swung Left	Normal	Swung Right	Swung Left	Normal.	Swung Right	Swung Left.
Vertical Posts										
1-2	L23U23	+ 15500								
3-4	L22U22	+ 62000								
5-6	L21U21	+ 62000								
7-8	L20U20	+ 52000								
9-10	U19L19	+ 32200								
11-12	L18U18	+ 18800								
13-14	L17U17	+ 4000								
15-16	L16U16	- 2000	+ 48000	- 29500				+ 21400	+ 31700	+ 51200
17-18	L15U15	+ 48000	+ 25200	+ 16200	- 38000	- 28500	- 14500	+ 51000	+ 52800	+ 50500
19-20	L14U14	+ 38000	+ 35500	+ 35000	- 57300	- 55000	- 58500	+ 47000	+ 46300	+ 44300
21-22	L13U13	+ 56900	+ 53000	+ 51200	- 56000	- 53000	- 56100	+ 40200	+ 40000	+ 37500
23-24	L12U12	+ 66000	+ 62000	+ 59500	- 53100	- 50200	- 52800	+ 32000	+ 32300	+ 29700
25-26	L11U11	0	0	0	0	0	0	0	0	0
27-28	L10U10	- 66000	- 62000	- 59500	+ 53100	+ 50200	+ 52800	- 23000	- 23500	- 20900
29-30	L9U9	- 69000	- 65000	- 62000	+ 45500	+ 42500	+ 44500	- 13700	- 14100	- 12000
31-32	L8U8	- 69400	- 66200	- 62500	+ 29800	+ 27400	+ 28200	- 4500	- 5700	- 3100
36-37	L6U6	0			- 6100					
38-39	L5U5	0			+ 14000					
40-41.	L4U4	0			+ 35000					
42-43	L3U3	0			+ 56700					
44-45	L2U2	0			+ 58900					
46-47	L1U1	0			+ 15000					

Article 4.
Maximum and Minimum Stresses.

The maximum and minimum stresses for all members of the truss are given in Table VII. These stresses are combined from the results in Tables II and VI.

TABLE VII

MAXIMUM AND MINIMUM STRESSES

Bottom Chords	Stress in Lbs.		Upper Chords	Stress in Lbs.		Diagonals	Stress in Lbs		Vertical Posts	Stress in Lbs.	
Member	Maximum	Minimum	Member	Maximum	Minimum	Member	Maximum	Minimum	Member	Maximum	Minimum
L24L23	+ 30000	+ 8000	L24U23	- 38000	- 10200	L23U22	-116000	- 26000	L23U23	+21200	+ 5700
L23L22	+112000	+ 26000	U23U22	- 29800	- 8000	L22U21	-128100	-39100	L22U22	+79300	+17300
L22L21	+196600	+ 52000	U22U21	-112200	-26200	L21U20	-126300	-52300	L21U21	+ 92600	+27100
L21L20	+275100	+ 85100	U21U20	-197300	-52100	L20U19	-124000	-55000	L20U20	+103000	+37500
L20L19	+335600	+118600	U20U19	-276500	-85500	L19U18	-122800	-54800	L19U19	+106800	+41300
L19L18	+381200	+149700	U19U18	-335300	-118300	L18U17	-118100	-55100	L18U18	+108600	+43100
L18L17	+415600	+179100	U18U17	-377500	-148000	L17U16	-100400	-41400	L17U17	+111200	+45700
L17L16	+437400	+204400	U17U16	-407700	-175000	L16U15	-106600	- 0	L16U16	+207700	+50900
L16L15	+453600	+199600	U16U15	-413000	-172800	U16L15	-111300	0	L15U15	+212900	+20900
L15L14	+463200	+154100	U15U14	-424000	-109900	U15L14	-109000	+15500	L14U14	+ 91300	-26400
L14L13	+427300	+110100	U14U13	-380500	- 70000	U14L13	-103500	+26500	L13U13	+99000	-31300
L13L12	+380800	+ 70000	U13U12	-328000	- 46300	U13L12	-111700	+36000	L12U12	+96000	-41800
L12L11	+327600	+ 46000	U12U10	-276400	- 39000	U12L11	-109000	+47500	L11U11	0	0
L11L10	+283300	+ 37300	U10U9	-281600	- 37400	L11U10	+86200	- 70000	L10U10	- 76000	+61800
L10L9	+296700	+54100	U9U8	-321000	- 54400	L10U9	- 76500	+73600	L9U9	+67500	-65300
L9L8	+353400	+86000	U8U7	-352200	- 85300	L9U8	-77100	+64800	L8U8	+74600	-56700
L8L7b	+375000	+125800	U7U6	-327000	-128500	L8U7	-81800	+63700	L6U6	+87700	+21900
L7bL7a	+343000		U6U5	- 313400	-110900	L7bU7	+160400	-37200	L5U5	+96800	+31000
L7aL6	+353800	+152800	U5U4	-276400	- 85300	L7aU7	+139000	-11500	L4U4	+9[illegible]800	+ 30300
L6L5	+338600	+133000	U4U3	- 213700	- 56800	U7L6	- 94900	-15200	L3U3	+91800	+26000
L5L4	+316700	+112100	U3U2	- 127300	- 29800	U6L5	- 95800	-27000	L2U2	+75600	+16900
L4L3	+276000	+ 85000	U2U1	- 36700	- 9700	U5L4	-111500	-42500	L1U1.	+20500	+ 5500
L3L2	+212300	+ 56300	U1L0	- 44100	- 11700	U4L3	-120500	-44500			
L2L1	+126700	+ 29700				U3L2	-125900	-39400			
L1L0	+ 36900	+ 9900				U2L1.	-124600	-27600			

Article 5.
Wind Bracing

a. Loading. The fixed loading for the wind stresses as given by the designers is 20 pounds per square foot of exposed surface of both trusses and also a moving load of 6000 pounds on the car.

For this investigation a dead wind load of 300 pounds per linear foot of truss is used. This is the figure recommended and used by various railroads and consulting engineers. The moving load of 6000 pounds is used in this investigation.

The dead panel load for the dock cantilever arm is 20.79 × 300 = 6240 pounds; for the central span 22.69 × 300 = 6800 pounds; for the furnace arm 21.42 × 300 = 6400 pounds. For the live load it is sufficiently accurate to consider the 6000 pounds concentrated at a panel point.

The total wind load is

considered is concentrated in the plane of the upper chord. This condition obtains on account of the construction (see Fig. 8), there being no lateral bracing in the plane of the lower chord or of the floor system.

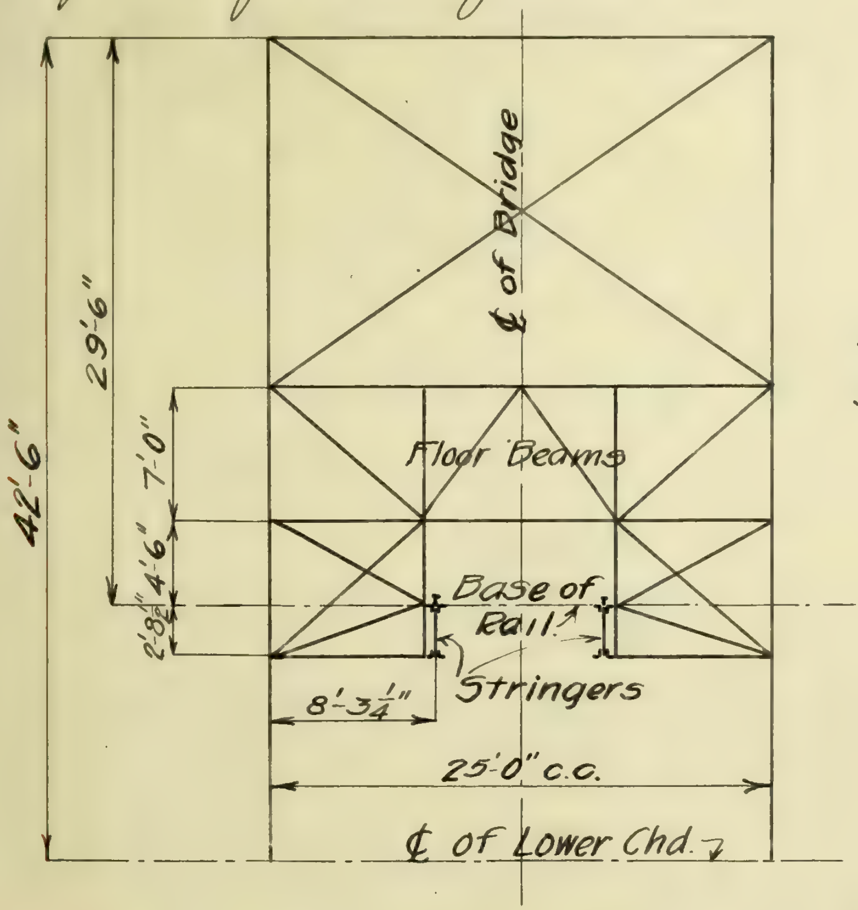


Fig. 8.
Section at U11L11
Showing Floor Bms.
Stringers, etc.

b. Reactions. The reactions for all loadings are computed by considering the bracing as partially continuous in the panel over the roller tower, i.e. no shear is transferred through this panel.

The live load reactions are computed with the car at the ends for the maximum stresses in the cantilever members, and with the car at each successive point in the center span. These reactions together with those for the dead load are given in Table VIII.

c. Stresses. The stresses in the wind bracing were computed by the ordinary V x sec φ method. These stresses are given in Table IX.

TABLE VIII.

REACTIONS FOR WIND BRACING.

Reaction for	R_1	R_2	R_3
Dead Load.	+53000	+34650	+67900
Car at Right End.	+6000	+4800	-4800
Car at Left End.	0	-4250	+10250
Car on Center Span.			
Point 1	0	+5300	+ 700
2	0	+4500	+1500
3	0	+3800	+2200
4.	0	+3000	+3000

TABLE IX.
STRESSES IN WIND BRACING.

Panel	Member	Max. Shear	Sec φ	Stress.
23	Strut	15400	1.0	+ 15400
	Diagonal		1.305	- 20100
22	S	21600	1.0	+21600
	D		1.305	-28200
21	S	27800	1.0	+27800
	D		1.305	- 36300
20	S	34100	1.0	+ 34100
	D		1.305	- 44500
19	S	40300	1.0	+40300
	D		1.305	-52600
18	S	46500	1.0	+ 46500
	D		1.305	- 60700
17	S	52800	1.0	+52800
	D		1.305	-69900
16	S	0	1.0	+59000
	D		1.305	0
15	S	33500	1.0	+33500
	D		1.35	- 45200
14	S	26100	1.0	+26100
	D		1.35	-35200
13	S	19300	1.0	+19300
	D		1.35	- 26000
12	S	12500	1.0	+12500
	D		1.35	- 16900
11	S	5700	1.0	+ 5700
	D		1.35	- 7700
10	S	10200	1.0	+ 10200
	D		1.35	- 13800
9	S	17500	1.0	+17500
	D		1.35	-23500
8	S	24800	1.0	+24800
	D		1.35	-33500
7	S	47800	1.0	+47800
	D		1.32	-63000
6	S	41400	1.0	+41400
	D		1.32	-54600
5	S	34900	1.0	+34900
	D		1.32	-46000
4	S	28500	1.0	+28500
	D		1.32	-37600
3	S	22100	1.0	+22100
	D		1.32	-29200
2	S	15700	1.0	+15700
	D		1.32	-20700

Article 6.
Investigation.

a. Tension Members. The allowable stress for tension members is taken at 16000 pounds per square inch. Table X shows the results of the investigation of the tension members.

The maximum stresses in Table X do not include the wind stresses in the upper chord members. Hence the tabular efficiencies are high. To show that the members are really efficient a typical computation is here shown.

The maximum wind stress in any member occurs in U16 U15 and its value is 200,400 pounds. The area of the member is 44.74 square inches. Therefore, the unit stress due to wind loads is $\frac{200,400}{44.74} = 4470$ pounds. The maximum unit stress due to dead and live loads is 9450 pounds. The total unit stress is, then, 9450 + 4470 = 13920 pounds which gives an efficiency of 114.8 per cent, using 16000 pounds as the allowable unit stress.

b. Compression Members. The allowable unit load for compression members is calculated from the formula

$$P = 16000 - 70\frac{l}{r}, \text{ in which,}$$

P = allowable unit load in pounds,

l = length of member, in inches,

and r = least radius of gyration, in inches.

The results of the investigation of the compression members are shown in Table XI.

The box girders under the fixed and roller towers are not investigated.

c. Alternate Stresses. Members which are subject to an alternation of stress are investigated in this section. The stress used is the sum of the actual stress and 50 per cent of the smaller of the two stresses. The allowable unit-loads given in sections a and b of this article are used here.

The results of the investigation of these members are given in Table XII.

TABLE X.
INVESTIGATION OF TENSION MEMBERS

Member.	Maximum Stress.	Section.	Area. Sq.In.	Unit Stress. Actual	Unit Stress. Allowable	Eff'cy %
Top Chords						
L24 U23	- 38000	2[12"x20½#	11.56	3290	16000	486.0
U23 U22	-29800	2[12"x20½#	11.56	2580	do	620.0
U22 U21	-112200	2[12"x25#	14.20	7910	do	202.0
U21 U20	-197300	2[12"x25#	20.58	9600	do	166.8
		2 Side Pl. 9"x7/16"				
U20 U19	-276500	2[15"x40#	28.70	9650	do	166.0
		1 Cov. Pl. 19"x15/16"				
U19 U18	-335300	2[15"x40#	34.40	9750	do	164.1
		1 Cov. Pl. 19"x5/8"				
U18 U17	-377500	2[15"x50#	37.98	9930	do	161.0
		1 Cov. Pl. 19"x1/2"				
U17 U16	-407700	2[15"x50#	43.29	9430	do	169.8
		2 Side Pl. 12"x5/16"				
		1 Cov. Pl. 19"x7/16"				
U16 U15	-413000	2[15"x50#	44.74	9200	do	174.0
U15 U14.	-424000	2 Side Pls 12"x7/16		9450	do	169.1
		1 Cov Pl. 19"x3/8"				
U14 U13	-380500	2[15"x45#	39.24	9680	do	165.1
		2 Side Pl. 12"x5/16"				
		1 Cov Pl. 19"x3/8"				
U13 U12	-328000	2[15"x45#	35.04	9380	do	170.8
		1 Cov Pl. 19"x1/2"				
U12 U11	-276400	2[15"x40#	30.95	8920	do	179.2
U11 U10		1 Cov Pl 19"x7/16"				
U10 U9	-281600	2[15"x40#	32.08	8750	do	182.8
		1 Cov. Pl. 19"x1/2"				
U9 U8	-321000	2[15"x50#	35.74	8700	do	184.0
		1 Cov. Pl. 19"x3/8"				
U8 U7	-352200	2[15"x50#	37.98	9280	do	172.4
		1 Cov. Pl. 19"x1/2"				
U7 U6	-327000	2[15"x40#	34.40	9500	do	168.3
		1 Cov. Pl. 19"x5/8"				
U6 U5	-313400	2[15"x40#	32.08	9760	do	163.9
		1 Cov. Pl. 19"x1/2"				
U5 U4.	-276400	2[15"x33#	28.36	9730	do	164.5
		1 Cov. Pl. 19"x1/2"				
U4 U3	-213700	2[15"x33#	25.98	8200	do	195.0
		1 Cov. Pl. 19"x5/16"				
U3 U2	-127300	2[12"x25#	14.20	8970	do	178.2
U2 U1	- 36700	2[12"x20½#	11.56	3180	do	503.5
U1 L0	-44100	2[12"x20½#	11.56.	3820	do	419.6

TABLE X.
INVESTIGATION OF TENSION MEMBERS.

Member	Maximum Stress	Section	Area Sq. In	Unit Stress Allowable	Unit Stress Actual	Effic'y %
Diagonals						
$L_{23}U_{22}$	-116000	4Ls 5"x3½"x$\frac{7}{16}$"	12.62	16000	9180	174.2
$L_{22}U_{21}$	-128100	4Ls 5"x3½"x$\frac{9}{16}$"	15.88	do	8080	198.1
$L_{21}U_{20}$	-126300	4Ls 5"x3½"x½"	14.25	do	8850	180.8
$L_{20}U_{19}$	-124000	4Ls 5"x3½"x½"	do	do	8700	184.3
$L_{19}U_{18}$	-122800	4Ls 5"x3½"x½"	do	do	8610	185.9
$L_{18}U_{17}$	-118100	4Ls 5"x3½"x½"	do	do	8280	193.2
$L_{17}U_{16}$	-100400	4Ls 5"x3½"x$\frac{7}{16}$"	12.62	do	7950	201.4
$L_{16}U_{15}$	-106600	2[s 12"x25#	14.20	do	7500	213.4
$U_{16}L_{15}$	-111300	2[s 12"x30#	16.01	do	6950	230.0
U_7L_6	-94900	4Ls 5"x3½"x$\frac{3}{8}$"	10.89	do	8720	183.5
U_6L_5	-95800	4Ls 5"x3½"x$\frac{3}{8}$"	do	do	8800	181.6
U_5L_4	-111500	4Ls 5"x3½"x$\frac{7}{16}$"	12.62	do	8800	181.6
U_4L_3	-128500	4Ls 5"x3½"x½"	14.25	do	9000	177.9
U_3L_2	-125900	4Ls 5"x3½"x$\frac{9}{16}$"	15.88	do	7920	202.0
U_2L_1	-124600	4Ls 5"x3½"x½"	14.25	do	8730	183.1
Diagonals in Wind Bracing						
$U_{23}U_{22}'$	-20100	1L 3"x2½"x$\frac{5}{16}$"	1.37	16000	14690	109.0
$U_{22}U_{21}'$	-28200	1L 3"x3"x$\frac{3}{8}$"	1.80	do	15640	102.1
$U_{21}U_{20}'$	-36300	1L 4"x3"x$\frac{7}{16}$"	2.56	do	14180	112.9
$U_{20}U_{19}'$	-44500	2Ls 3"x2½"x$\frac{5}{16}$"	2.79	do	15950	100.2
$U_{19}U_{18}'$	-52600	2Ls 4"x3"x$\frac{5}{16}$"	3.73	do	14100	113.6
$U_{18}U_{17}'$	-60700	2Ls 4"x3"x$\frac{3}{8}$"	4.33	do	14020	114.1
$U_{17}U_{16}'$	-69900	2Ls 4"x3"x½"	5.62	do	12430	128.7
$U_{16}U_{15}'$	0	2Ls 4"x3"x½"	5.62	do	0	∞
$U_{15}U_{14}'$	-45200	2Ls 4"x3"x½"	5.62	do	8050	198.8
$U_{14}U_{13}'$	-35200	1L 4"x3"x$\frac{7}{16}$"	2.68	do	13150	114.0
$U_{13}U_{12}'$	-26000	1L 4"x3"x$\frac{3}{8}$"	2.17	do	12000	133.3
$U_{12}U_{11}'$	-16900	1L 3"x3"x$\frac{5}{16}$"	1.47	do	11480	139.4
$U_{11}U_{10}'$	-7700	1L 3"x3"x$\frac{5}{16}$"	1.47	do	5240	305.0
$U_{10}U_9'$	-13800	1L 3"x3"x$\frac{5}{16}$"	1.47	do	9400	170.2
U_9U_8'	-23500	1L 3"x3"x$\frac{5}{16}$"	1.47	do	16000	100.0
U_8U_7'	-33000	2Ls 4"x3"x$\frac{7}{16}$"	5.12	do	6450	248.2
U_7U_6'	-63000	2Ls 4"x3"x$\frac{7}{16}$"	5.12	do	12300	130.0
U_6U_5'	-54600	2Ls 3"x3"x$\frac{3}{8}$"	3.60	do	15150	105.7
U_5U_4'	-46000	2Ls 3"x3"x$\frac{5}{16}$"	2.94	do	15640	102.2
U_4U_3'	-37600	1L 4"x3"x$\frac{7}{16}$"	2.68	do	14020	114.0
U_3U_2'	-29200	1L 3"x3"x$\frac{3}{8}$"	1.80	do	16200	98.8
U_2U_1'	-20700	1L 3"x2½"x$\frac{5}{16}$"	1.37	do	15100	105.9

TABLE XI.
INVESTIGATION OF COMPRESSION MEMBERS.

Member	Maximum Stress	Section	Area Sq In.	Unit Load Allowable	Unit Load Actual	Eff'y %
Bottom chords.						
L24L23	+ 30000	2⊏ 12"×20½#	12.06	12300	2480	495.0
L23L22	+112000	2⊏ 12"×25#	15.70	12000	7130	168.1
L22L21	+196600	2⊏ 12"×25# 2 Side Pl. 9"×½"	23.70	11400	8300	137.3
L21L20	+275100	2⊏ 15"×33# 1 Cov Pl 19"×9/16"	30.49	13100	9010	145.1
L20L19	+335600	2⊏ 15"×45# 1 Cov.Pl. 19"×9/16"	37.17	13000	9020	144.0
L19L18	+381200	2⊏ 15"×40# 1 Cov. Pl. 19"×5/8" 2 Side Pl. 12"×5/16"	42.90	12900	8870	145.3
L18L17	+415600	2⊏ 15"×45# 1 Cov. 19"×5/8" 2 Side Pl. 12"×5/16"	45.85	12900	9070	142.1
L17L16	+437400	2⊏ 15"×45# 1 Cov.Pl. 19"×5/8" 2 Side. Pls 12"×7/16"	48.86	12700	8950	142.0
L15L14	+463200	2⊏ 15"×50# 1 Cov. Pl. 19"×5/8" 2 Side Pl 12"×7/16"	51.80	12700	8950	142.0
L14L13	+427300	2⊏ 15"×50# 1 Cov. Pl 19"×9/16" 2 Side Pl. 12"×5/16'	47.61	12700	8980	141.3
L13L12	+380800	2⊏ 15"×50# 1 Cov. 19"×5/8"	41.30	12700	9230	137.4
L12L11	+327600	2⊏ 15"×40# 1 Cov. Pl. 19"×5/8"	35.40	12700	9230	137.4
L11L10	+283300	2⊏ 15"×33# 1 Cov Pl. 19"×9/16	30.49	12700	9280	136.9
L10L9	+296700	2⊏ 15"×40# 1 Cov. Pl. 19"×5/8"	35.40	12700	8390	151.2
L9L8	+353400	2⊏ 15"×50# 1 Cov Pl 19"×9/16"	40.11	12700	8800	144.2
L8L7b	+375800	2⊏ 15"×50# 1 Cov. Pl. 19"×5/8"	41.30	12700	9080	139.9
L7bL7a	+343000	Box Girder Section.				
L7aL6	+353800	2⊏ 15"×50# 1 Cov. Pl. 19"×½"	39.00	12700	9080	139.9
L6L5	+338600	2⊏ 15"×50# 1 Cov. Pl. 19"×7/16"	37.80	12700	8960	141.7

TABLE XI.

INVESTIGATION OF COMPRESSION MEMBERS.

Member	Maximum Stress	Section	Area Sq. In.	Unit Load		Effic'y %
				Allowa'le	Actual	
Bottom	Chords.					
L_6L_4	+316700	2 [s 15"×45#, 1 Cov Pl 19"×$\frac{1}{2}$"	35.98	12800	8790	145.7
L_4L_3	+276000	2 [s 15"×40#, 1 Cov Pl 19"×$\frac{3}{8}$"	31.83	12900	8670	148.8
L_3L_2	+212300	2 [s 12×25#, 2 Side Pl 9"×$\frac{9}{16}$	24.82	11300	8650	130.8
L_2L_1	+126700	2 [s 12"×25#	14.70	12000	8610	139.40
L_1L_0	+36900	2 [s 12"×20$\frac{1}{2}$#	12.06	12400	3060	406.0
Vertical	Posts.					
$L_{23}U_{23}$	+21200	2 [s 12"×20$\frac{1}{2}$#	12.06	12400	1760	704.0
$L_{22}U_{22}$	+79300	do	do	12100	6580	184.0
$L_{21}U_{21}$	+92600	do	do	11800	7680	146.8
$L_{20}U_{20}$	+103000	do	do	11300	8550	132.0
$L_{19}U_{19}$	+106800	do	do	10500	8850	118.6
$L_{18}U_{18}$	+108600	do	do	9600	9000	106.6
$L_{17}U_{17}$	+111200	do	do	12600	9220	136.5
$L_{16}U_{16}$	+207700	2 [s 15"×40#	23.52	12600	9200	137.0
$L_{15}U_{15}$	+212900	do	do	12600	9150	137.9
L_6U_6	+87700	2 [s 12"×20$\frac{1}{2}$#	12.06	12600	7280	173.0
L_5U_5	+96800	do	do	12600	8030	156.9
L_4U_4	+96800	do	do	11200	8030	139.3
L_3U_3	+91800	do	do	11800	7600	155.0
L_2U_2	+75600	do	do	12300	6280	196.0
L_1U_1	+20500	do	do	12600	1700	740.0
Wind	Bracing					
Tower Struts	+52800	4 Ls 6"×4"×$\frac{3}{8}$"	14.44	9500	3660	260.0
All other Struts	+41400	4 Ls 3"×2$\frac{1}{2}$"×$\frac{5}{16}$"	6.48	7000	6370	110.0

TABLE XII.

INVESTIGATION OF MEMBERS SUBJECT TO ALTERNATE STRESS.

Member	Stress Used	Section	Area Sq. In.	Unit Load Allowable	Unit Load Actual	Eff'cy %
Diagonals						
U15 L14	-116800	2[12" x 30#	16.83	16000	6920	231.0
	+23300		17.64	5870	1320	445.0
U14 L13	-117800	do	16.83	16000	7000	229.0
	+42000		17.64	6360	2380	267.4
U13 L12	-129700	do	16.83	16000	7700	207.6
	+54000		17.64	6550	3060	214.0
U12 L11	-132800	do	16.83	16000	7880	203.2
	+71300		17.64	6550	4050	161.9
L11 U10	+121200	do	17.64	6550	6860	95.5
	-105000		16.83	16000	6230	256.7
L10 U9	-113300	do	16.83	16000	6730	238.0
	+110400		17.64	6360	6250	102.0
L9 U8	-109500	do	16.83	16000	6500	246.0
	+97200		17.64	6360	5510	115.4
L8 U7	-113700	do	16.83	16000	6750	237.0
	+95600		17.64	5870	5430	108.1
L7b U7	+179000	2[15" x 40#	23.52	13220	7610	173.8
	-55800		23.02	16000	2420	660.0
L7a U7	+144800	2[15" x 33#	19.80	13310	7310	182.0
	-17300		19.30	16000	896	1782.0
Posts.						
L14 U14	+104500	2[12" x 25#	14.70	12580	7100	177.0
	-39600		14.20	16000	2785	575.0
L13 U13	+114700	do	14.70	12580	7800	161.1
	-47000		14.20	16000	3310	484.0
L12 U12	+116900	do	14.70	12580	7950	158.3
	-62700		14.20	16000	4410	363.0
L11 U11	0	2[12" x 20½#	12.06			∝
	0					∝
L10 U10	-106900	2[12" x 25#	14.20	16000	7530	212.7
	+92700		14.70	12580	6300	200.0
L9 U9	+100200	do	14.70	12580	6810	184.5
	-98000		14.20	16000	6900	232.0
L8 U8	+103000	do	14.70	12580	7000	179.4
	-85100		14.20	16000	6000	267.0

Article 7.
Conclusion.

The investigation given in the preceding pages shows that this crane was, in the main, designed in accordance with the best specifications for such structures. In only a very few members did the efficiency fall below 100 per cent; indeed, for a large majority of the members the efficiency is very high, so high, in fact, as to cause doubt as to the economy of construction. However, the crane when built was the first of its kind, and that may have led the designers to be particularly careful.

On the whole, then, it may be said that this crane shows careful and safe design, although somewhat uneconomical.